ANALYSIS OF PACIFIC ENROUTE STRUCTURE IN SUPPORT OF C-5M "SUPER GALAXY"

GRADUATE RESEARCH PAPER

June 2015

Christopher J. Keller, Major, USAF

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DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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Abstract

The C-5M, “Super Galaxy,” brings significantly more capability to strategic airlift fleet with more powerful and efficient engines. Given the strategic imperatives in the Asia-Pacific region, the C-5M is vitally important to overcome the “tyranny of distance” throughout the Pacific AOR. It is the aim of this research to serve airlift planners with an operationally relevant tool, results and analysis to bridge from national defense strategy to smart tactical employment of a new weapon system. Specifically, this research paper sought to answer questions addressing optimal routes and the impact of routing decisions on tiered enroute support. This quantitative study used regression analysis of aircraft performance and route enumeration. The research identified that the C-5M’s capability may justify new route alternatives. These new routes may impact tiered aircraft maintenance capability outside the continental United States. Recommendations to implement more effective and efficient routing are discussed.

“Let us not attempt to reconcile contradictions, but firmly embrace a rational alternative.”
--Alexander Hamilton, The Federalist no. 23

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I would like to express my sincere appreciation to my research advisor, Lt Col Adam Reiman, for his guidance and support throughout the course of this research effort. His insights and experience were certainly appreciated. I would, also, like to thank my sponsor, Col David Mott, from 60th Air Mobility Wing for both the support and latitude he provided to me in this endeavor. I am also indebted to the many educators who sparked a lifetime of learning in me. Special thanks go to Maj Jason Roberts, who provided me reliable support and was always available to answer my questions.

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ANALYSIS OF PACIFIC ENROUTE STRUCTURE IN SUPPORT OF C-5M "SUPER GALAXY"

I. Introduction

General Issue

Air Mobility Command (AMC) has reached Initial Operating Capability (IOC) with the C-5M, "Super Galaxy." The new Mission Design Series (MDS) brings significantly more capability to strategic airlift fleet with more powerful and efficient engines (Refer to Table 1). The potential exists for improved mission efficiency and effectiveness to deliver the most substantial of the combatant commander's requirements. This paper will identify why it is important to consider the C-5M as a new major weapon system in the context of today's national military strategy, identify current operational practices, quantify potential alternatives to the fixed enroute support structure, and analyze positive and negative implications if the Air Force implemented proposed changes.

Table 1. Summary of Strategic Airlift Capabilities

MDS	Name, Manufacturer	ACL stns (1)	Pallet Positions	Range @ 120 KLbs (3)	Source
C-5M	"Super Galaxy", Lockheed	141 (2)	36	4,800 NMs	T.O.
C-5B	"Galaxy", Lockheed	89	36	3,800 NMs	AFPAM10-1403
C-17A	"Globemaster III", Boeing	65	18	2,400 NMs	AFPAM10-1403
B-747	"Jumbo Jet", Boeing	120	33	4,978 NMs	AFPAM10-1403
KC-10	"Extender", McDonnell-Douglas	60	23	4,369 NMs	AFPAM10-1403

1. Allowable cargo load (ACL) maximum calculated for 3200NM (AFPAM 10-1403, 2011:12)

2. Allowable cargo and fuel combinations for varying operating weights of 375,000 to 425,000 pounds (1C-5M-1, 2014:2293)
3. Range does not consider aerial refueling

The C-5 weapon system has a storied history of both successes and modest failures. It has been employed in wartime contingency operations since the 1973 aerial resupply of Israel to today's retrograde operations from Afghanistan. In Air Force vernacular, it is an infamous "hangar queen". The historical mission capable rate is approximately 56% (Knight, 2008). Therefore, an extensive two-fold modernization effort is underway: the Avionics Modernization Program (AMP) and the Reliability Enhancement and Re-engining Program (RERP). The C-5As are retiring per the 2013 National Defense Authorization Act (NDAA). The program of record is 52 C-5B/Ms by FY16. See Appendix C for the C-5 fleet breakout (current as of February 2015). Given any complex project management, there are anecdotal errors and cost growth, but the modernization effort may extend the service life of the C-5 into 2040 or beyond (Lockheed Martin, 2014).

The C-5 is unique because it can carry any air cargo class: bulk, oversized, outsized, and passengers (troop compartment is an overhead rear cargo area). Bulk cargo is palletized on 463L platform (88×108 inches pallet with a balsa wood core and thin aluminum skin). Oversized cargo is non-palletized rolling stock or is larger than bulk that extends past the 463L platform (JP 3-17, 2013:GL-11). Outsized cargo is also non-palletized cargo that does not fit on a C-130 aircraft and represents the largest cargo class (From JP 1-02, outsize is "a single item that exceeds 1,000 inches long by 117 inches wide by 105 inches high in any one dimension"). Requirements that exceed the C-5's volume limitations need to move via alternate surface modal options like rail or ship.

Figure 1 shows a distribution of pallet weights from Dover AFB (KDOV) to Ramstein AB (ETAR) in a 6-month period in 2012. The average pallet weight is about 4,000 pounds. For a "fully loaded" C-5 with 36 pallet positions, it is reasonable to expect a payload of approximately 160,000 pounds.

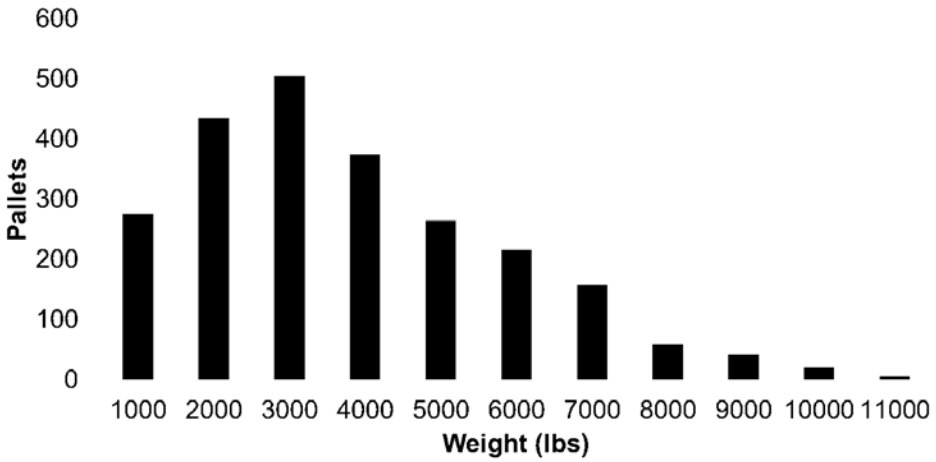


Figure 1. Pallet weight distribution

(Reiman, et al., 2013:6)

This research will demonstrate that pallet utilization should change to accommodate potentially larger C-5M payloads (greater than 260,000 lbs) and improve aircraft load factors for efficient operations. The payload over range tradeoff is very important over oceanic distances in the Pacific, but syncing demand with supply to maximize aircraft capacity is not an easy problem.

There are many confounding variables faced by decision makers in the business of airlift, but commercial and military airlift differ substantially. Typically, military airlift planners receive requirements that are largely driven by events that are infrequent, like "a bolt from the blue." An airlift planner cannot ignore a validated user request because it is not cost-effective, nor wholly ignore an entire area of responsibility like the

Pacific because oceanic distances are inconvenient. In contrast, the commercial passenger airline industry operates over a network structure that is published in advance and user demand that is less variable in the medium-term.

Figure 2 shows aggregated payloads (short tons) for C-5 aircraft from 1 Jan 2012 to 31 Dec 2014 originating from Travis AFB to various destinations throughout Asia-Pacific. The lines represent vectors with a direction between origin-destination and the relative magnitude given by the thickness of the line, but not the actual routes (or network) flown nor the period variation in demand.

Row Labels	TOTAL_PAX	TOTAL_CGO	TOTAL_PAYLOAD
KSUU - PHIK	8,650	2,688	4,418
KSUU - RKSO	681	2,577	2,713
KSUU - RJTY	2,189	1,939	2,377
KSUU - RODN	1,801	1,888	2,248
KSUU - PGUA	163	233	266
KSUU - PWAK	20	151	155
KSUU - YSRI	0	17	17
Grand Total	13,504	9,494	12,194

Figure 2. Cargo flow from Travis' C-5 aircraft into the PACOM Area of Responsibility AOR (2012-2014)

Given an origin and destination with requirements, air mobility planners have control over the choice of intermediate stop(s) within the global network of airfields. The decision of picking optimal intermediate stops will be explored in greater detail.

The optimization problem is the problem of finding the best solution from all feasible solutions. An important logistics optimization problem is the vehicle routing problem (VRP), which seeks to minimize the total cost between a single origin and several customer delivery destinations by a fleet of vehicles (Dantzig, 1959:217-222). A special sub-set of the classic VRP is the strategic airlift problem (Toth, 2001).

The vehicle routing problem has been extensively explored in the context of strategic airlift (Lambert, et al., 2007) (Baker, et al., 2001). In general, routes between the origin and destination may contain multiple intermediate stops, such as a fuel stop. However, the linear programming model must be computationally tractable. An important sub-problem is the deliberate elimination of intermediate locations; hence, fewer combinations of routes to solve a tractable problem in polynomial time. The

modeling dilemma: potentially optimal route(s) are dismissed. Thus, the conclusions from strategic airlift models are "preferred" routes across a larger global network. Operational planners should not ignore feasible routes between the origin and destination.

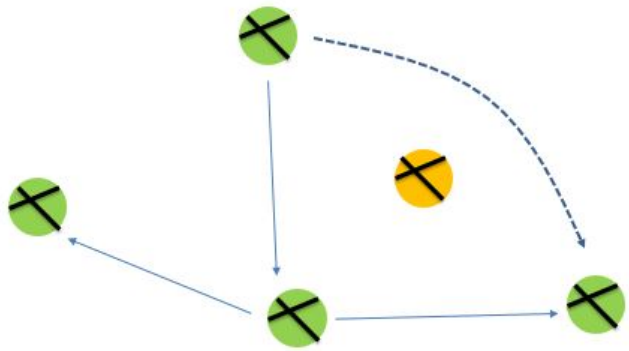


Figure 3. Simplified "preferred routes" in a network

Unwittingly, air mobility planners may ignore optimal routes with intermediate stops that are outside this "preferred" network. Figure 3 illustrates this simple choice to stop at an intermediate location or overfly. The ability to quickly generate multiple feasible routes from an unabridged list of airfields is explored further in the research. In 2007, Air and Space Power Journal published an article, "*Intellectual Modernization of the C-5.*" It drew a qualitative contrast between a C-17 Expeditionary Airlift Squadron (EAS) construct and a typical C-5 airlift stage operation to advocate for a more "expeditionary mindset" in the C-5 community (Dillon, 2007). The article recalled, "Done right, a modernized and expeditionary C-5 may finally 'revolutionize global mobility airlift,' as former CINCMAC General Estes predicted in 1966." Now, may be the time to further incorporate an "expeditionary mindset" in the air mobility community.

The purpose of this research is to provide operational level airlift planners with improved insight into route alternatives beyond the preferred fixed enroute support locations.

Problem Statement

Dover AFB acquired the C-5M before Travis AFB. Routes have adjusted to the longer legs in the European theater, such as Dover (KDOV) to Incirlik (LTAG). Less routing has been adjusted in the Pacific area of responsibility. Given the improved aircraft performance, it is practical to investigate the implications of routing aircraft through a fixed enroute support network, known as the Global Air Mobility Support System (GAMSS).

Research Objectives/Questions

The goal of the research is to exploit the range-payload curve of the C-5M and compare operationally relevant scenarios to current fixed, tiered enroute support operations located outside the Continental United States (OCONUS):

1. At a given payload, origin and destination to airlift, what is the best selection of enroute stops to most effectively/efficiently move the cargo?
2. Based on optimal routes, what are the associated implications on the current state of fixed OCONUS tiered, enroute support operations?
3. What are risks to re-structure tiered pre-positioned operations?

Research Focus

The research was conducted to examine the C-5M's improved performance and assess the relative performance of AMC's strategic aircraft types over specified origin-

destination (OD) pairs. Given current defense strategic guidance and the continued delivery of C-5Ms to Travis AFB (CA), the geographic focus of this research will be in the Pacific AOR. Airlift planners may realize more effective (increased maximum payload) operations or improved efficiency (reduce fuel) with a quick comparison of feasible routing between OD pairs.

Methodology

The methodology used for this research was a two-part quantitative analysis: (1) linear regression model(s) of aircraft performance, and (2) enumeration of potential route alternatives. The primary effort was to code the C-5M performance characteristics into the Air Force Institute of Technology (AFIT) route generation algorithm(s) in JavaScript (Reiman, 2014). The model generates feasible routes with zero to five intermediate stops (e.g. fueling, transload) between the selected origin and destination. Using OD pairs within the Pacific AOR, the model was used to generate high value routes for the C-5B, C-5M and C-17 aircraft. Then route alternatives are sorted based on a factor of interest, such as maximum payload, cargo throughput, or cycle time. Finally, the top routes are plotted with the Great Circle mapper tool (www.gcmap.com) to better visualize the data.

Assumptions/Limitations

The following are assumptions/limitations of this research:

1. Great circle routing uses elliptical earth distance formula (Vincenty, 1975)
2. Recommendations are limited to no-wind optimized routing and standard day aircraft performance factors.

3. Planning factors such as airfield latitude, elevations, runway length, and pavement strength are pulled from Digital Aeronautical Flight Information File (DAFIF) and are assumed to be current.
4. Routing does not consider organized track system(s), e.g. North Atlantic Tracks.
5. Some airfields may be unavailable due to working Maximum On the Ground (MOG) or airfield damage.
6. OD pairs and payload weights are not indicative of actual Time-Phased Force Deployment data (TPFDD), which would require analysis at the SECRET or TOP SECRET classification level.
7. Any proposed movement of fixed enroute locations may have secondary or tertiary effects, like basing commitments related to geopolitical risk factors, are considered outside the scope of this research paper.

Implications

The intent of this research is to better exploit the capabilities of the C-5M aircraft within the global mobility enterprise. A deep understanding of range-payload tradeoffs will aid airlift planners at the operational level of war. While the research focus is on the optimal use of the C-5M to meet airlift cargo demand, any recommendations must consider the second-order effects on force seasoning, including aircrew and maintenance personnel. These effects cannot be dismissed. Furthermore, the research does not evaluate the total investment (or divestment) related to the allocation of scarce resources that govern working maximum on the ground of airfields. Nor does the research evaluate aircraft fleet mix based on decisions related to network design.

Additionally, the air mobility enterprise is fully dependent on commercial partners to meet surge wartime requirements. It is foolish to ignore their contributions during times of less than full mobilization. The research does not investigate the interdependence of organic and commercial airlift fleet mix. Therefore, criticism is expected of this research since the subject of strategic airlift is narrowly focused on C-5M, but the intent is to better inform the operational science of strategic airlift.

II. Literature Review

Chapter Overview

The purpose of this chapter is to establish the bookends for this research. First, the strategic environment is surveyed from current national security documents. Next, joint doctrine is reviewed for ground support to strategic airlift routing. Then the modernization efforts of the C-5 program are addressed, to include the current mission capability rate. The literature review concludes with a cursory report of combat airlift employment tactics. This provides an adequate background on the strategic environment, enroute support, and C-5 program to later discuss research methodology and results.

Strategic Environment

The 2014 Quadrennial Defense Review (QDR) states, “If deterrence fails: U.S. forces will be capable of defeating a regional adversary in a large-scale, multi-phased campaign; and denying the objectives of or imposing unacceptable costs on a second aggressor in another region.” This strategy requires mobility assets that can carry significant combat payloads over an extended range. “Determining the most cost-effective mix of these various approaches will require careful analysis considering technology advancements and expected fiscal constraints between now and 2020.” (Dempsey, 2012). From the Unified Command Plan, the United States Transportation Command (USTRANSCOM) is the “global distribution synchronizer” and answers the call of the combatant commander to rapidly flow forces forward (POTUS, 2011). In the Air Force’s defining document, Executive Order 9877 explicitly records "...airlift" in the roles and mission of the service (Public Law 253, 1947). More recently in 2010, the

Chief of Staff designated the Commander of Air Mobility Command as the "core function lead integrator for 'Rapid Global Mobility,'" which includes responsibility for doctrine, organization, training, materiel, leadership, personnel, and facilities (DOTMLPF) (HAF, 2009). It is the aim of this research to serve airlift planners with an operationally relevant tool, results and analysis to bridge from national defense strategy to smart tactical employment of a new weapon system.

The national defense strategy illustrates the breadth and depth of United States' strategic partnerships in the Pacific area of responsibility, such as India, Korea, Australia, Guam and Japan. "The United States supports India's rise as an increasingly capable actor in the region, and we are deepening our strategic partnership, including through the Defense Trade and Technology Initiative" (Hagel, 2014:39). Furthermore, security obligations exist to maintain peace on the Korean Peninsula by effectively working with allies and other regional states to deter and defend against provocation from North Korea, which is actively pursuing a nuclear weapons program (OSD, 2013:8). "In FY 2014, the Department funded key aspects of the rebalance to the Asia-Pacific region by creating a more operationally resilient Marine Corps presence in the Pacific, undertaking key presence initiatives in Australia, and investing in Guam as a joint strategic hub" (OSD, 2013:Annex H). As part of DoD's broader efforts for stability in the Asia-Pacific region, the United States will maintain "a robust footprint in Northeast Asia while enhancing our presence in Oceania and Southeast Asia." (Hagel, 2014:14). Given the nation's strategic defense imperatives in the Asia-Pacific region, origin and destination pairs were selected from these operationally relevant scenarios to apply to the research methodology.

Global Air Mobility Support System (GAMSS)

Figure 4 illustrates the Global Air Mobility Support System (GAMSS) which combines those ground support functions essential to safe, effective air cargo operations (aerial port, maintenance, command and control) located in both the continental United States (CONUS) and outside the continental United States (OCONUS) (JP 3-17, 2013:I-8). Additionally, Active Duty and Air Reserve Component strategic airlift units located throughout the CONUS provide a significant amount of fixed capability, to include fuel support and warehousing facilities.

Figure 4. The current GAMSS fixed enroute laydown

As the lead command, Table 2 and 3 explain AMC's tiered maintenance capabilities for enroute support at various locations (AFI21-101_AMC Sup, 2011:A15.3)

Table 2. Definition of tiered enroute maintenance capabilities

Capability	Tier I	Tier II	Tier III	Tier IV
Operations	**24/7 w/AMCC**	**24/7 w/AMCC**	**Less than 24/7**	**No Enduring Presence**
Maintenance	**WMOG= 3 or more** **R&R, Predictive MX, Limited Backshop** **2 or More MDSs** **15 Acft/Day Throughput**	**WMOG= 1 or more** **R&R For 2 MDSs** **5-14 Acft/Day Throughput**	**WMOG= 0-1** **0-4 Acft/Day Throughput**	**As mission dictates** **Rotational Forces** **As mission dictates**

(AFI21-101_AMC Sup, 2011:A15)

Table 3. Tier Status of Enroute Bases

Tier I	Tier II	Tier III		Tier IV	
Ramstein	**Spangdahlem**	**Aviano**	**Singapore**	**Fairford**	**Ascension**
Hickam	**Rota**	**Cairo**	**Sigonella**	**Iwakuni**	**Antigua**
	Andersen	**Clark**	**Osan**	**Kandahar**	**U-Taphao**
	Elmendorf	**Misawa**	**Lajes**	**Bahrain**	**Christchurch**
	Kadena	**Moron**	**Diego Garcia**	**Djibouti**	**Balad**
	Yokota	**Tel Aviv**	**Pope**	**Souda Bay**	
	Incirlik	**Richmond**	**Mildenhall (no mx)**	**Ali Al Salem**	
	Al Udeid	**Kuwait**		**Bagram**	
		Eielson		**Aruba**	

(AFI21-101_AMC Sup, 2011:A15)

The network of tiered maintenance locations informs the risk decision made by airlift planners when choosing an intermediate stop. Since the C-5 has a reputation for "breaking," maintenance recovery options are an important consideration.

C-5 History and Modernization

For over 40 years, the C-5 has provided strategic delivery of national sovereign options for the United States.

> "The first C-5 employed under operational wartime conditions in October 1973 in support of an aerial resupply operation to Israel called Operation NICKEL GRASS. The C-5 carried an average of 73 tons to the C-141's 28 tons. Additionally, the C-5 transported outsized cargo including 155mm howitzers, 175mm cannons, M-60 and M-48 battle tanks, Sikorsky CH-53D helicopters and McDonnell Douglas A-4 Skyhawk aircraft fuselages." (AMC Museum, 1991)

The C-5 is an important part of the inter-theater airlift capability. Developed in the 1950's, the C-5 is designed to move outsized and oversized cargo over oceanic distances. The C-5 flew approximately 23% of Operation DESERT SHIELD/STORM missions, delivering 38% of airlifted cargo (Matthews, et al. 1992:42). At the kickoff of Operation ENDURING FREEDOM/IRAQI FREEDOM (OEF/OIF), it flew approximately 30% of all OEF missions and 23% percent of all OIF missions, delivering almost 48% of the airlifted cargo (ASPJ, 2003:36). In the modern context, the C-5M will likely carry a reduced total percentage when the commercial partner movements are added in and since the MAF switched the primary strategic airlifted from the C-141 to the C-17 (with double cargo capacity) in the mid-1990s. The C-5, which carries over 250,000 pounds of cargo, continues to be a very effective platform when it flies. The aircraft has been plagued by reliability issues and associated maintenance costs. If the mission capable rates can be improved, the C-5 may continue to be a valuable part of the strategic airlift fleet.

Due to a 56% mission reliability rate, the Avionic Modernization Program (AMP) and Reliability Enhancement & Re-Engineering Program (RERP) were implemented to

address unreliable systems and improve capability (Knight, 2008). According to Air Force Life Cycle Management (AFLCM) C-5 Division Mobility Directorate, "RERP will enable the C-5M to achieve wartime mission requirements by increasing fleet availability (mission capable and departure reliability rates), reducing Total Ownership Costs (TOC), and improving aircraft performance" (WR-ALC, 2011). In accordance with FY13 National Defense Authorization Act and the DoD's submission of the 2018 Mobility Capabilities Assessment to Congress, the Air Force will continue retiring C-5A aircraft (USTRANSCOM, 2013).

Table 4. C-5 Aircraft Inventory
(SAF/FMB, 2015)

	Active	Reserve	Total
FY15	36	22	58
FY16	36	16	52

As of December 2014, there were 64 C5 aircraft (SAF/FM, 2014:Vol 2-135). From the FY16 Presidential Budget submission, the C-5 re-capitalization effort is nearing the half-way point and planned total aircraft inventory of 52 C-5B/Ms by FY17. The C-5M has already tallied impressive results to affect closure of retrograde requirements from Afghanistan to Persian Gulf ports over 70 days, 3 C-5Ms, five crews, moved 17.6 million pounds of cargo with a max load of 280,880 pounds (to include 8 pieces of rolling stock) (Huseman, 2014).

Appendix C summarizes the current C-5 fleet bed-down (as of March 2015). As of the time of this literature review, it is significant that Travis AFB has 10 aircraft in RERP, and is the western most CONUS C-5 home station.

AMC uses a mission capable rate (a proportion of uptime versus downtime) to assess the availability of the fleet. The AMC standard for the C-5M mission capability (MC) rate is 75%. Figure 5 is a summary of LIMS-ev data, which suggests that current MC rate is approximately 63% as of 2014.

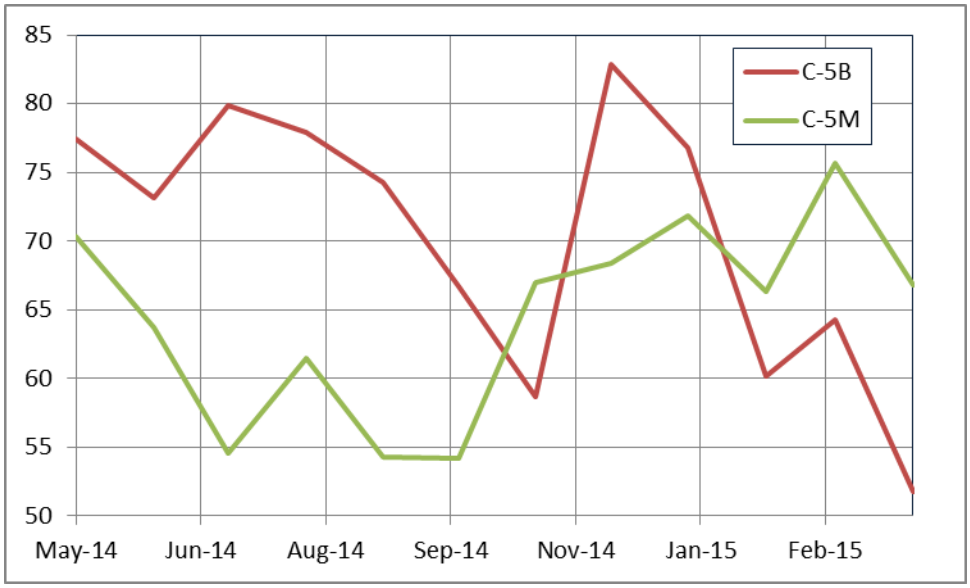


Figure 5. C-5M/B Mission Capable Rates from May 2014 to February 2015

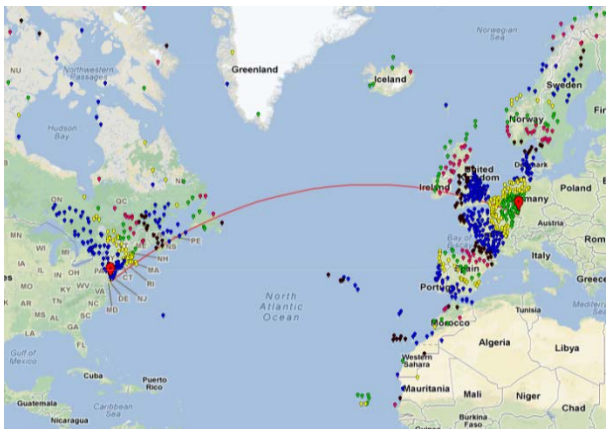
A safe hedge is to say, the AMC standard is not yet achieved given "small fleet dynamics," or yet more optimistically, "break-in" time for preventative maintenance practices needed to take hold. Regardless, time will allow for more aircraft deliveries and the future is bright with possibility.

Given a modernized fleet and the current strategic context, the C-5M should be evaluated anew by operational airlift planners for its unique niche in the strategic airlift fleet.

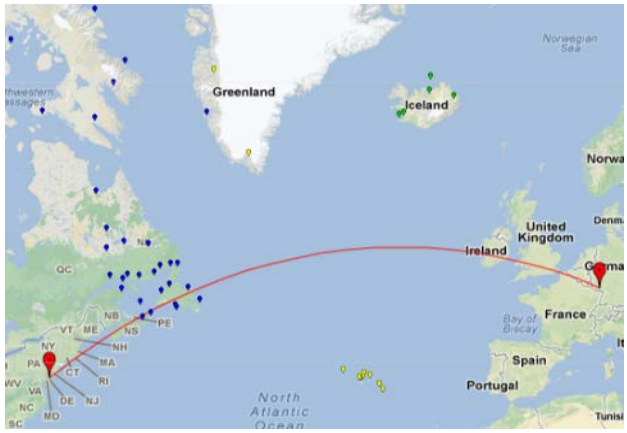
AFIT Route Analyzer

The AFIT Route Analyzer was created by AFIT PhD student Lt Col Adam Reiman. The model was created to aid in strategic airlift planning using JavaScript. The user may select the aircraft type, crew complement, staging of crews and trans-load operations. The analyzer needs an origin and destination airfield (four letter ICAO airport identification) to cycle through routing alternatives (Reiman, 2014).

The routing problem is complicated by the sub-problem "on whether to go direct, stop for gas, or trans-load … by the interaction between fuel, payload, and distance." (Reiman, 2014:43). Since DAFIF includes over 5,000 global airfields (Figure 6), Reiman proposed a minimum-cutoff distance model to remove suboptimal enroute stops between OD pairs, thereby "rapidly creating a set of high value routes for analysis" (Reiman, 2014:45).



No Minimum Cutoff Distance



700 NM Minimum Cutoff Distance

(Reiman, 2014:25)

Figure 6. Impact of minimum cutoff distance on nodal reduction

The Air Force Institute for Technology (AFIT) route analyzer conducts nodal reduction, generates routes and sorts routes on the basis of cargo throughput, fuel efficiency, time or cost (Reiman, 2014:100). The routes may be compared by the following measures: distance, maximum payload, cycle-time, cargo throughput for maximum payload, cargo throughput for a planned payload, fuel efficiency for maximum payload and fuel efficiency for a planned payload. The maximum payload fuel efficiency output is calculated by dividing the cargo throughput per day by the fuel consumed per day based on the maximum payload (Reiman, 2014). This output is useful in determining fuel efficiency when the planned payload is unknown. The maximum function of this output will load the aircraft with as much payload as possible for the designated route. The algorithm used for route alternative generation did not previously include C-5M aircraft. The required regression analysis of the C-5M performance data is a primary focus of the research methodology.

Other Relevant Research

The other "bookend" to this research is the sound tactical employment of the weapon system. One tactical consideration is the return of an airdrop mission to the C-5M. Given the improved reliability, the notion for airdrop qualified C-5M crews has been examined. An AFIT quantitative analysis concluded the C-5M was cost prohibitive compared to the C-17 due to a restriction of 18 pallets/180,000lb (Weitz, 2012). It is also

important to note the tactical training efforts of C-5M aircrew during Advanced Combat Operations Training (ACOT) hosted at Travis AFB.

> "This scenario-based training supports the full spectrum of operations in both permissive and contested battle space while delivering the most realistic and efficient learning experience possible. The ultimate goal is to give crews enhanced applied knowledge to meet the combatant commander's requirements." Maj Jason Roberts 60 AMW

Since the C-5 community lost special-missions in 2003, successful lessons observed must inform better tactics, techniques and procedures (TTPs). The application of combat TTPs are linked to this operational research topic. Given ACOT observations, there may be a sound argument for recurring C-5 aircrew low-level training requirement(s). A summary of current ACOT employment tactics may be viewed at the following link.

While this research assumes no-wind routing, the effect of wind optimized routing has also been well studied. The regions around 30° N/S (sub-tropical jet) and 50°-60° N/S (polar jet) are areas where temperature changes are the greatest; therefore, the winds in the upper atmosphere are the strongest (NOAA, 2011) . The jet stream can reach speeds up to 239 kts. Aviation regulators have built organized route structures, like the North Atlantic Tracks (NATs), to take advantage of the upper level jet. To date, the impact of wind is not addressed by the AFIT route analyzer used in the methodology. However, the ability to rapidly create high value routes with decision quality data is compelling for planners to make better decisions.

Airlift planners must choose routes under conditions of uncertainty (weather, maintenance or enemy threat). From AMCI 90-903, *Aviation Operational Risk Management (AVORM) Program*, AMC has implemented well intentioned efforts to

control variation and mitigate risk in airlift operation. From the AVORM checklist, "Item 15. Enroute Locations Mission Support Event…definition: level of support available from enroute personnel, bases, airfields, command and control." (AMC, 2014:3) But, rewards, like more payload or better fuel efficiency, may be lost in organizational paradigm of risk that limits options for intermediate fuel stops. The risk versus reward tradeoff is necessary to mention because the research results may lie outside the "comfort area" of some air mobility planners.

Summary

Airlift planners must apply sound operational science at the nexus of national defense strategy and tactical employment. Given the strategic imperatives in the Asia-Pacific region, OD pairs are selected from these operationally relevant scenarios. Likewise, the C-5M is vitally important to overcome the "tyranny of distance" throughout the Pacific AOR. The improved C-5M capability may justify new route alternatives, but may impact tiered aircraft maintenance capability. Therefore, the C-5M needs to be programmed into the AFIT route analyzer to compare route metrics between selected OD pairs.

III. Methodology

Chapter Overview

To assess the performance capabilities of the C-5M, three essential steps were used. First, regression analysis was performed on flight data from aircraft performance manuals (Air Force Technical Order 1C-5M-1-1, i.e. takeoff, cruise, landing performance data). Second, the route generation algorithm was coded in JavaScript with regression coefficient terms. Third, selected OD pairs were sequenced and sorted based on maximum payload, cargo throughput and fuel efficiency.

Regression Analysis

To determine the climb, cruise and descent fuels, regressions were performed on flight data from aircraft performance manuals, as well as critical field length. The climb regression equation is Equation 1 (Reiman, 2014). The β parameters for Equation 1 are shown in Table 5. The lowest adjusted R^2 for any of the climb regressions was 0.9823. The descent regression equation is Equation 3 and the β parameters for Equation 3 are shown in Table 7. The lowest adjusted R^2 for any of the descent regressions was 0.987.

$$\boldsymbol{\varphi_C = \beta_0 + \beta_1\alpha + \beta_2\alpha^2 + \beta_3\alpha^3 + \beta_4\omega + \beta_5\omega^2 + \beta_6\omega^3 + 10^{-6}\beta_7\alpha^2\omega^3 + 10^{-6}\beta_8\alpha^2\omega^3} \quad (1)$$

Where:

φ_C = Time to Climb in minutes, Fuel to Climb in Klbs or Distance to Climb in NMs
α = Altitude in Thousands of Feet
ω = Aircraft Gross Weight in Klbs at Climb Start

Table 5. Climb Regression Terms

	C-5M Climb φ_C		
	Time	Fuel	Dist
β_0	-25.94	-102.44	-10.33
β_1	0.472	1.729	0.354
β_2	-0.01	-0.0082	-0.0072
β_3	0.0003	0.00088	7.99E-05
β_4	0.1132	0.4315	0.0377
β_5	3.4E-07	-0.0006	-4.9E-05
β_6	8.4E-08	3.04E-07	2.3E-08
β_7	3.3E-07	3.93E-06	-4.8E-08
β_8	1.4E-05	4.32E-05	1.96E-05

The regression equation for specific range is Equation 2 (Reiman, 2014). Table 6 shows the β terms for the C-5M. The lowest adjusted R^2 for any of the specific range regressions was 0.9985.

$$\boldsymbol{\theta = \beta_0 + \beta_1\alpha + \beta_2\alpha^2 + \beta_3\omega + \beta_4\omega^2 + \beta_5\alpha\omega} \quad (2)$$

Where:

θ = Specific Range in NMs per Klbs
α = Altitude in Thousands of Feet
ω = Aircraft Gross Weight in Klbs

Table 6. Specific range regression terms

	C-5M
β_0	21.15
β_1	0.5514
β_2	0.0006
β_3	-0.0229
β_4	1.2E-05
β_5	-0.0004

$$\varphi_D = \beta_0 + \beta_1\omega + \beta_2\omega^2 + \beta_3\alpha + \beta_4\alpha\omega \quad (3)$$

Where:

φ_D = Time to Descend in minutes, Fuel to Descend in Klbs or Distance to Descend in NMs
ω = Aircraft Gross Weight in Klbs at Descent Start
α = Altitude in Thousands of Feet

Table 7. Descent regression terms

	C-5M Descent φ_D		
	Time	Fuel	Dist
β_0	-6.992	-0.3963	-59.96
β_1	0.0275	0.001998	0.1708
β_2	-2.2E-5	-0.0000016	-0.0001
β_3	0.4101	0.025938	2.9764
β_4	0.000295	0.0000248	0.0007

Using data from Air Force Technical Order 1C-5M-1-1, a regression was performed that determined CFL θ given temperature and elevation as seen in Equation 4 (Reiman, 2014). The coefficients and adjusted R^2 for critical field length are shown in Table 8.

$$\theta = \beta_0 + \beta_1\alpha + \beta_2\alpha^2 + \beta_3\varphi_{adj} + \beta_4\omega + \beta_5\omega\alpha + \beta_6\omega\alpha^2 + \beta_7\omega\varphi_{adj} + 8\varphi_{adj}{}^2 + \beta_9\varphi_{adj}\alpha \quad (4)$$

Where:

θ = Critical field length in feet
α = Elevation in thousands of feet
ω = Aircraft Gross Weight in Klbs
φ_{adj} = Airfield temperature in degrees Celsius

Table 8. Critical field length $\boldsymbol{\theta}$ regression coefficients and adjusted R^2

	C-5M
β_0	-5107
β_1	-168.7
β_2	-19.2
β_3	-26.1
β_4	15.3
β_5	0.485
β_6	0.0553
β_7	0.0751
β_8	0
β_9	0

Lt Col Reiman, PhD. updated the route generation algorithm with C-5M performance functions using JavaScript.

Route Enumeration

To narrow the scope of analysis, OD pairs were selected based on operationally relevant scenarios from current strategic defense guidance in the Pacific AOR. Table 9 lists the selected pairs originating out of Travis AFB (KSUU). Table 10 lists the selected pairs originating out of Dover AFB (KDOV) to analyze polar route options into the Pacific. The analysis of the routes was limited to one or two intermediate stops, and routing options did not consider intermediate stops in China or Russia. Figure 7 provides geographic frame of reference for OD pairs.

Table 9. Selected Travis/SUU- OD pairs

	From ICAO	To ICAO		From ICAO	To ICAO
1	KSUU	RJTY	6	KSUU	RPLC
2	KSUU	PGUA	7	KSUU	WSAP
3	KSUU	YSRI	8	KSUU	FJDG
4	KSUU	RKSO	9	KSUU	VTBU
5	KSUU	RODN	10	KSUU	VIDX

Table 10. Selected Dover/DOV- OD Pairs

	From ICAO	To ICAO
1	KDOV	PAED
2	KDOV	FJDG

Figure 7. Map of selected Travis AFB OD pairs

Summary

The methodology for this research enhanced the AFIT Route Analyzer model with C-5M performance data. First, the AFIT Route Analyzer model was programmed

with the climb, cruise and descent fuels from aircraft performance manuals. Once programmed, the model provided quick and accurate route alternatives between OD pairs for the C-5M, C-5B and C-17. The highest rated routes at maximum payload, maximum cargo throughput and fuel efficiency for each OD pair were selected for comparison. Next, the data is visualized on an orthographic projection of the Earth in the results and analysis section.

IV. Analysis and Results

Chapter Overview

The C-5M's payload over range capability is clearly demonstrated by the choice of route. The implications for the choice of top routes are discussed in this section.

Results of Scenarios

Figure(s) 8-10 provide a summary of the top routes for each OD pair on the basis of maximum planned cargo payload, cargo throughput, and fuel efficiency for following aircraft types: C-5M, C-5B and C-17. The routing includes one intermediate stop between origin and destination, and two intermediate stops to right of the dashed line.

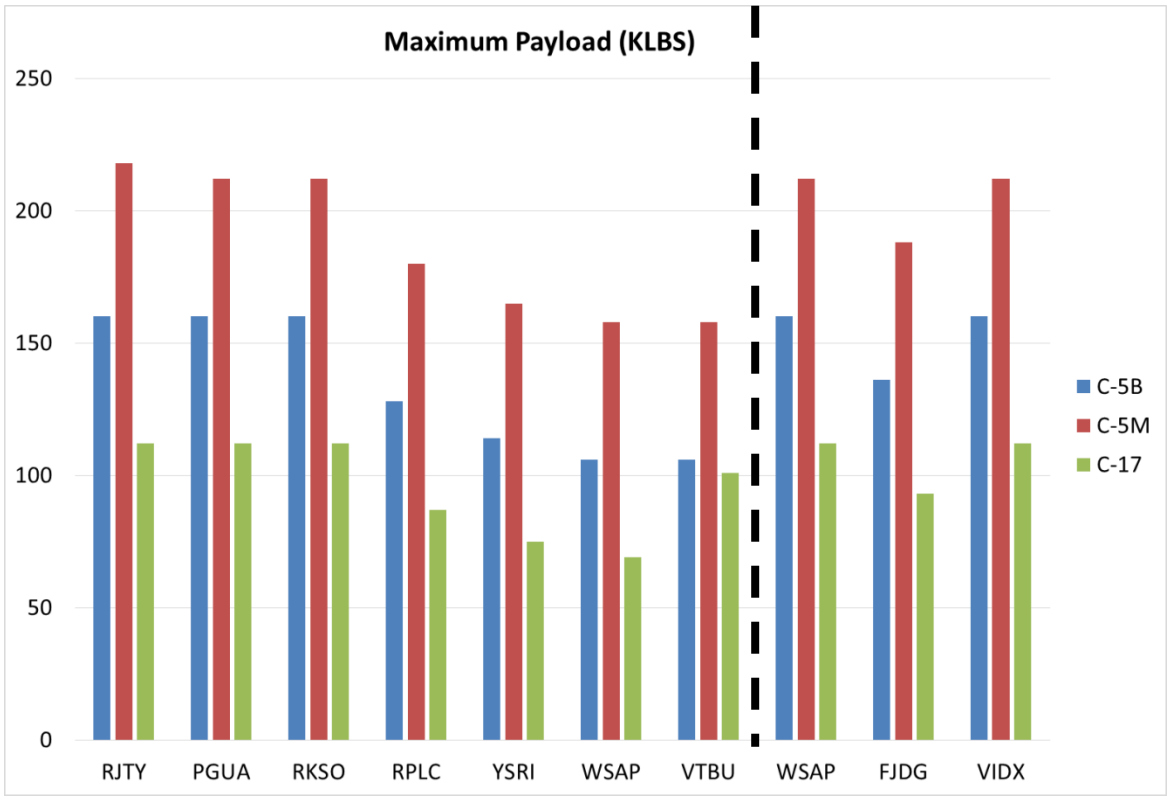


Figure 8. Summary of Maximum Payload for optimal OD pair (KSUU-XXXX)

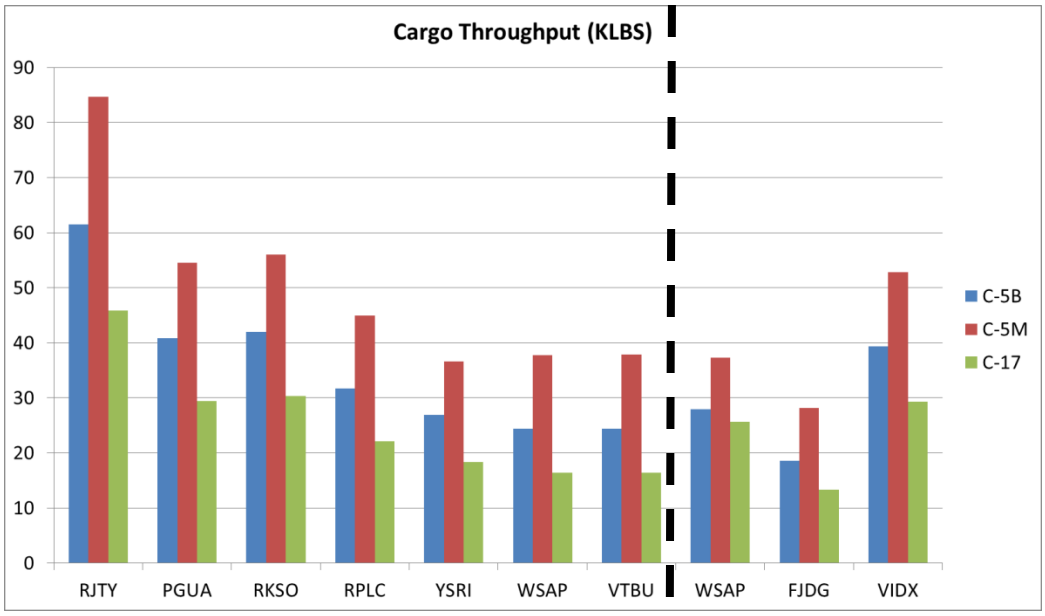


Figure 9. Summary of Cargo Throughput for optimal OD pair routes (KSUU-XXXX)

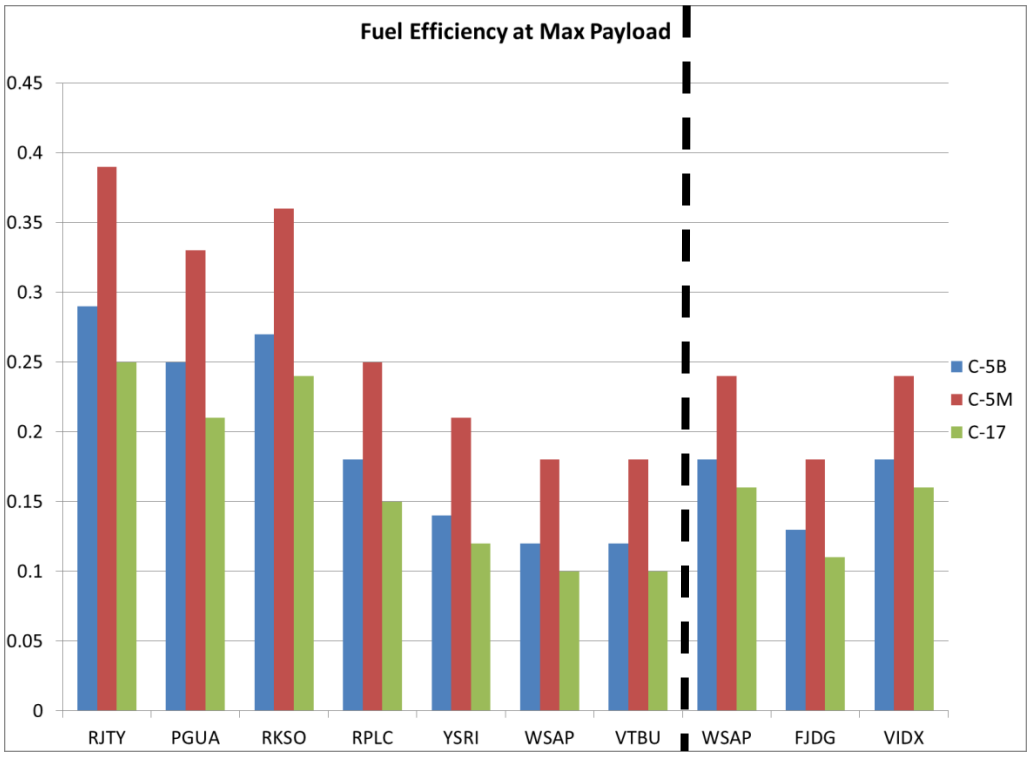


Figure 10. Summary of Fuel Efficiency Index for optimal OD pair routes (KSUU-XXXX)

The average increase in maximum payload and cargo throughput of the C-5M over the C-5B at approximately 6000 nautical miles range is 40% with one intermediate stop. At approximately 6000 nautical miles, there is an average 38% increase in fuel efficiency from the C-5M at maximum payload over the C-5B. The average increase in maximum payload is 31% and 17% in cargo throughput of the C-5M over the C-5B at approximately 7800 nautical miles range. At approximately 7800 nautical miles, there is an approximate 34% increase in fuel efficiency from the C-5M at maximum payload.

Figure 11, shows the best routes with one stop originating out of Travis AFB (KSUU). The thickness of the red line was used to show relative percentage increase in throughput of the C-5M over the C-5B. This highlights the strategic value of Shemya (PASY), Wake Island (PWAK) and Tahiti (NTAA). Hickam Field (PHIK) is relatively far from the great circle path of most routes originating from Travis.

Figure 11. Orthographic projection of optimal routes between OD pairs

Figure 12. KSUU-RKSO network flow versus optimal route (red)

Figure 12 shows the relative amount of cargo flown by C-5's from Travis to Osan (KSUU-RKSO by route from 2012-2014 (Appendix B). Due to routing into Hickam Field (PHIK), there is a less than "optimal" cargo flow to Osan AB, Republic of Korea (RKSO). The optimal route (KSUU-PASY-RKSO) has a maximum payload of over 200 Klbs and a cargo throughput of 55 Klbs cargo per day and is shown by the route in red. In contrast, the route KSUU-PHIK-RJTY-RKSO was used for 45% of the cargo flown between Travis and Osan from 2012-2014. The use of Joint Base Elmendorf-Richardson (PAED) rather than Shemya (PASY) is addressed later in this section. A similar analysis is shown for the KSUU-RJTY pair in Figure 13.

Figure 13. KSUU-RJTY Network versus optimal route

The optimal routing for north-east Asia, e.g. RJTY, RODN, RKSO, also stops at Shemya AK (PASY), which poses logistical challenges due to a lack of tiered enroute maintenance. Therefore, operational planners should consider increasing enroute support at Shemya. According to Alaska's Department of Transportation (DoT), Joint Base Elmendorf-Fort Richardson (PAED) is less than 9.5 hours from 90% of the industrial world and is also a reasonable alternative to PASY. The routes are compared in Figure 14. Additionally, the 715th Air Mobility Operations Group (AMOG) provides tiered enroute support at PAED.

	Route 1	Route 2
Route Details	KSUU-PASY-RKSO	KSUU-PAED-RKSO
Route map	Great Circle Map	Great Circle Map
Max Payload	212.23 KLbs	183.91 KLbs
Cargo Throughput	80.25 Klbs per day	68.86 Klbs per day

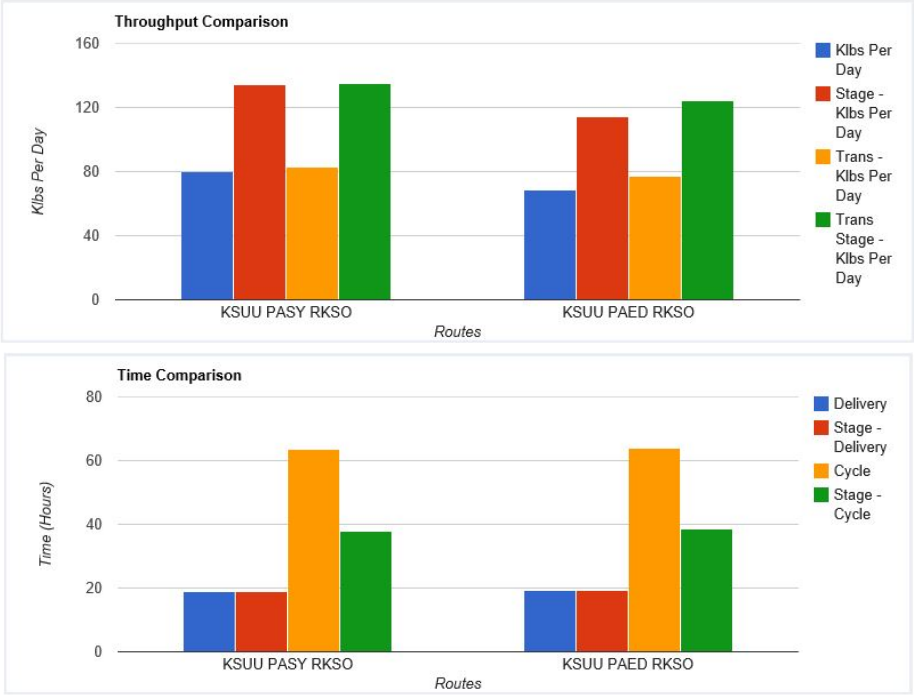


Figure 14. Intermediate stop at PASY versus PAED

With great circle routing, the C-5M can range into the Pacific AOR from Dover AFB (KDOV). Table 11 presents convincing data that linking cargo flows from KDOV to the Pacific does not require routing via a western CONUS port. Figure 15 shows PAED and FJDG are near anti-podal distance (~8150NM vs ~12000NM from KDOV) within the Pacific AOR.

Table 11. Dover (KDOV) Routing Comparison

	KDOV-KGTF*-PAED	KDOV-LROP**-FJDG
Delivery Time (Hours)	15.16	40.09
Max Payload (Klbs)	268.89	141.54
Fuel Efficiency (Klbs cargo per day per Klbs fuel)	.66	.16

*KGTF / Great Falls Int'l Montana / Longest Runway: 10,502'x150'
**LROP / Henri Coanda, Bucharest, Romania / Longest Runway: 11,484' x 148'

Figure 15. Antipodal distance between Diego Garcia (FJDG) to JB Elmendorf-Richardson (PAED)

Perhaps due to past reliability issues with the C-5B, Australia has been served by other organic aircraft or commercial tenders for channel operations into Richmond (YSRI). Given rotational US Marines presence in Darwin, there is now a need to monitor the demand into Australia and evaluate the reliability tradeoffs with the C-5M. The proposed optimal routing at maximum payload is KSUU-NTAA-YSRI. Given strategic guidance to consider anti-access/area-denial threats, the C-5M's direct delivery capability is also important to consider.

These results above pose an antithetical value proposition, "what is the ability of the C-5M over a C-5B when an enroute stop is destroyed by enemy action?" Given a lower density of suitable alternative intermediate stops in the Pacific compared to European theater, the ability of enemy action to constrain freedom of movement must be considered. Table 12 is a comparison of AFIT route analyzer for a theater direct delivery mission between Travis AFB (KSUU) and Yokota (RJTY) or Osan (RKSO. It is shows between a 65-77% increase in maximum payload on theater direct delivery.

Table 12. C-5M vs. C-5B direct delivery mission from KSUU to RJTY/RKSO

Route: KSUU-RJTY	**C-5M**	**C-5B**
Delivery Time (Hours)	14.6	15.06
Max Payload (Klbs)	127	76
Fuel Efficiency (Klbs cargo per day per Klbs fuel)	.26	.15
Route: KSUU-RKSO	**C-5M**	**C-5B**
Delivery Time (Hours)	15.6	16.06
Max Payload (Klbs)	108	57
Fuel Efficiency (Klbs cargo per day per Klbs fuel)	.20	.11

Investigative Questions Answered

1. For a given requirement, origin and destination to airlift, what is the best selection of enroute stops to most effectively/efficiently move the cargo?

With the C-5M performance data coded in the AFIT route analyzer, the algorithm quickly produces a "top ten list" of high value routes between an origin and destination. The airlift planner can chose the appropriate sorting criteria (maximum payload, cargo throughput, or fuel efficiency) to balance route effectiveness versus efficiency.

2. Based on optimal routes, what are the associated implications on the current state of fixed OCONUS tiered, enroute support operations?

With regard to routing, (a) an enroute stop for fuel may allow for a greater payload and better fuel efficiency across oceanic distances in the Pacific, (b) current fixed enroute support locations are not always optimal intermediate stops, and (c) if airlift planners only choose existing tiered enroute locations then potentially better routing solutions are ignored. However, a myopic focus on the route optimization problem risks a sub-optimal solution to the overall system. In the opinion of the researcher, a significant factor that needs further consideration is maintenance force seasoning.

3. What are risks to re-structure tiered pre-positioned operations?

There are various operational risk factors to consider while routing a C-5M. Foremost, if the aircraft breaks then what are the maintenance recovery options. The achieved mission capable (MC) rates will inform resourcing through the global network. The literature review established that recent C-5M reliability is better than historic C-5B rates. A MC rate of 75% versus 55% drives different operational design considerations. There is less risk to operations from using tiered enroute locations, but there is also a cost

in increased time, increased fuel consumption, and decreased payload movement capability. The research suggests that increasing tiered enroute maintenance support at Shemya (PASY), Wake Island (PWAK) and Tahiti (NTAA) will increase maximum cargo throughput in the Pacific AOR. At least, a maintenance recovery team (MRT) may be dispatched or tailored contingency response forces sent to provide required enroute support. The effective command and control of MRT sub-processes by TACC/XOCL (Rupp, 2008). Due to the total cost of investment/divestment and a myriad of other geo-political judgments, the research omitted basing decisions for reasons of scope.

Summary

Based on the assumptions of this research, the aim of this research has been achieved to better serve airlift planners with an operationally relevant tool, results and analysis to bridge from national defense strategy to smart tactical employment of a new weapon system. There is empirical evidence that cargo flown from Travis AFB into the Pacific may improve using an improved methodology for routing decisions. With the C-5M performance data in the AFIT route analyzer, airlift planners can make better decisions to balance reward (more payload, better fuel efficiency) against the risk (delay enroute due to maintenance).

V. Conclusions and Recommendations

Conclusions of Research

In conclusion, the C-5M is a "weapon of mass delivery" and is poised to deliver the combatant commanders' sovereign options for another 30 years (TACC, 2014). The data garnered from the AFIT Route Analyzer supports the researcher's goal to locate optimal routing between a given origin and destination with respect to payload. This research also supports the researcher's second aim to examine tiered enroute locations. There is more study required to fully examine the risk versus reward tradeoffs amongst various routes.

Significance of Research

In collaboration with Lt Col Reiman, PhD (AFIT), the improvement of the AFIT route analyzer with C-5M performance data was an original contribution. With the tool, an airlift planner has the ability to quickly produce high value routes for various strategic airlifters. The operational benefit of a higher aircraft load factor (ratio of the actual load to the optimal load) is readily apparent. However, pallet utilization by weight is easier said than implemented due to volume restrictions, i.e. "cube out" before "gross out". Therefore, maximum payload is not routinely used by airlift planners, but its value is critical to accurate load factor determination during planning (Reiman, 2013).

$$\textbf{\textit{Load Factor}}\ (\textbf{\textit{Weight}}) = \frac{\textbf{\textit{Actual Cargo Weight}}}{\textbf{\textit{Computer Flight Plan computed Payload Maximum}}}$$

The average pallet weight needs to increase in order to achieve a C-5M load factor of 70% or better. The average pallet weight needs to be at least 5,000 pounds at aerial ports of debarkation served by the C-5M.

This research offers insight into the significant improvement in the range-payload curve of the C-5M over the C-5B and other strategic airlifters. This asymmetric advantage in "global reach" may counter anti-access/area denial strategies imposed by sovereign state actors or other antagonists. The C-5M can fly around or over denied territory. This research may assist operational planners in a dynamic twenty-four hour air tasking cycle.

Recommendations for Action

First, undertake verification, validation and accreditation (VVA) of the JavaScript tool for inclusion into operational airlift planners toolkit at Air Mobility Divisions of geographic combatant commander's Air Operations Center (AOC) and the functional 618 AOC (TACC). The lead integrator should be TACC/XOG for new routing and the inclusion of the tool into planning efforts. Planners may need to think anew with respect to routing possibilities and the tool can rapidly produce high value routes.

The AMC staff should publish new air mobility planning factors (AFPAM 10-1403), especially with regard to the C-5M allowable cargo load. A new version of the planning guide should explain the importance of the range-payload decision, to include the trade-off between fuel and payload. As written, the guide offers quick "rules of thumb," but the efficiencies gained from choosing wisely among feasible alternatives can

save real dollars. Moreover, the staff should set specific targets for pallet utilization (average pallet weight 5Klbs) at aerial ports of debarkation (Travis AFB and Dover AFB) that drives a goal for higher aircraft load factors (greater than 50%) for the C-5M.

It's time to look at the en route writ large and balance tiered support. Based on this research, additional resourcing at strategic locations at Shemya (PASY), Wake Island (PWAK) and Tahiti (NTAA) will increase maximum cargo throughput in the Pacific AOR. The USAF Expeditionary Center (EC) in conjunction with A4O and A4M should evaluate the best placement of maintenance and aerial port equipment in the en route system. At least rotational forces may be utilized at these locations and an update to the tiered enroute locations list (Table 3) with Tier IV status. The findings offer more empirical evidence and support previous research that Joint Base Elmendorf-Ft Richardson (PAED) is a strategic location (Sponseller, 2014). These locations deserve the attention of operational airlift planners for intermediate enroute stops and may require additional resourcing for safe effective strategic airlift operations.

Recommendations for Future Research

The decision to resource (investment and divestment cost) fixed tired enroute OCONUS location demands nuance to weigh geo-political risks. The basing debate should be informed by operational science. A useful visual framework has been developed to balance interdependent operational factors for the C-5B and C-5M (Soban, 2011). The C-5M will impact the quantitative science of working MOG, but a more advanced model that accounts for factors like maintenance, fuel, ramp space, ramp strength, and material handling equipment capabilities must be developed to weigh those

factors. The Joint Distribution Process Analysis Center (JDPAC) may have a simulation modeling technique better suited to analyze working MOG.

The paper did not cite the current AMC enroute strategy. AMC A5/8 uses the C-17 to plan routes and tier enroute locations. Thinking beyond Phase 0 of operational planning, there may be need to re-balance resourcing based on other criteria. A future research methodology should consider the strategic fleet mix in the problem statement and implications on tiered enroute support.

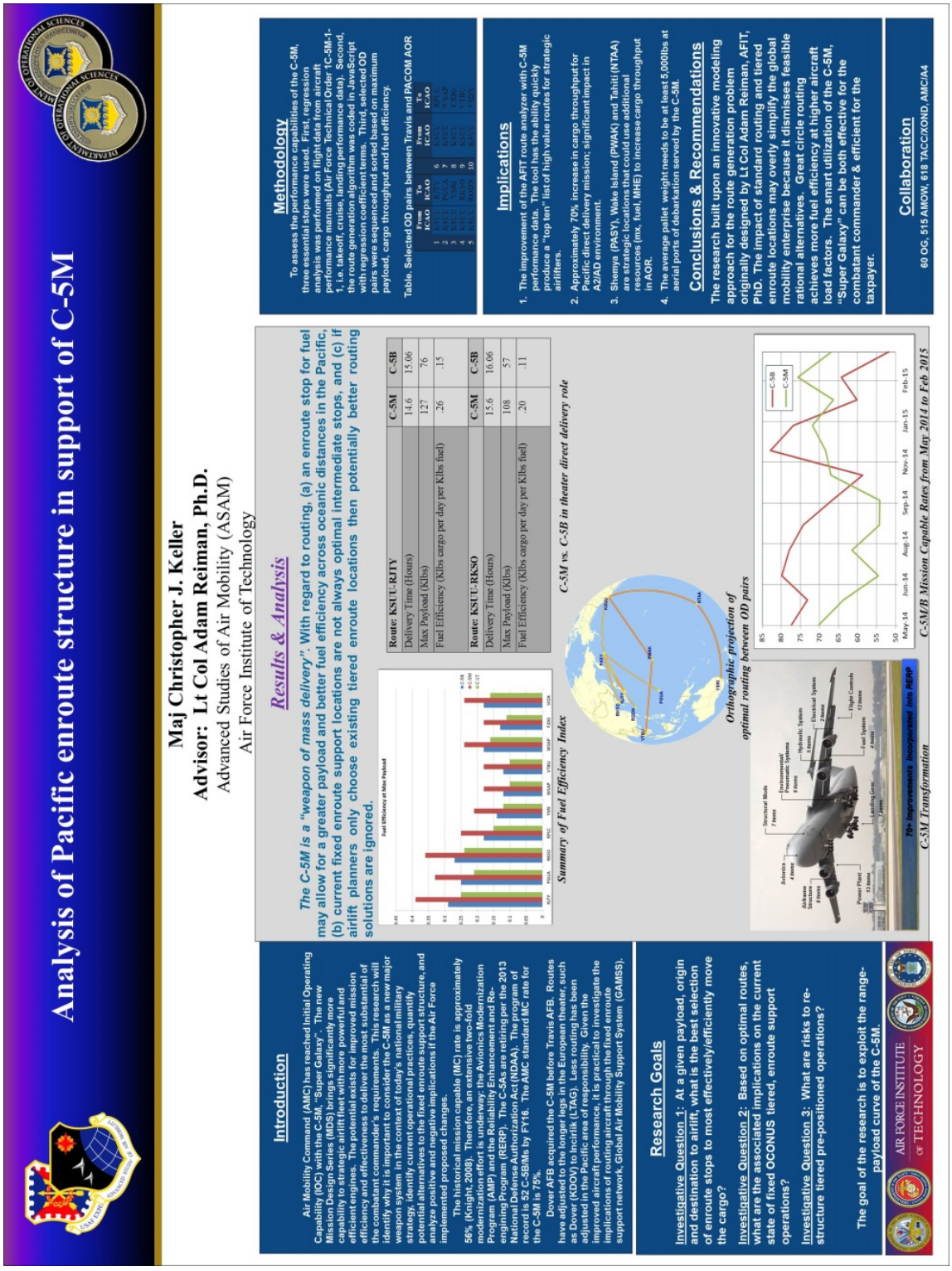
During the course of the literature review, Travis AFB is uniquely situated near the Port of Oakland and Defense Logistics Agency (DLA) San Joaquin. A joint study between USTRANSCOM and National Highway Traffic Safety Administration (NHTSA) to investigate the system design between the aerial port and surface transportation modalities (highway infrastructure capacity, rail links, and/or key bridges safety ratings) related to congestion problems in this strategic Pacific gateway during a wartime surge is also an auspicious area for future research.

Summary

The research built upon an innovative modeling approach for the route generation problem originally designed by Lt Col Adam Reiman, AFIT, PhD. Air Mobility Command has sought various fuel efficiency initiatives, but has ignored the impact of standardized routing. The impact of standard routing and tiered enroute locations may overly simplify the global mobility enterprise because it dismisses feasible rational alternatives. Great circle routing achieves more fuel efficiency at higher aircraft load

factors. The smart utilization of the Air Force's newest strategic airlifter can be both effective for the combatant commander and efficient for the taxpayer.

Appendix A. Storyboard



Appendix B. Travis AFB C-5 payloads from 1 Jan 2012 to 31 Dec 2014

Travis AFB C-5 payloads from 1 Jan 2012 to 31 Dec 2014

Row Labels	TOTAL_PAX	TOTAL_CGO	TOTAL_PAYLOAD
⊟KSUU - PHIK	8,650	2,688	4,418
KSUU-PHIK	8,408	2,537	4,218
KSUU-KSUU-PHIK	184	64	101
KSUU-PAED-PHIK	19	45	49
KSUU-0I61-PHIK	15	28	31
KSUU-PHIK-RJTY-RKSO-RODN-PHIK	0	9	9
KSUU-KSUU-KSUU-PHIK	15	6	9
KSUU-PHIK-PHIK	9	0	2
⊟KSUU - RKSO	681	2,577	2,713
KSUU-PHIK-RJTY-RKSO	294	1,178	1,237
KSUU-PAED-RJTY-RKSO	107	273	294
KSUU-PHIK-RODN-RKSO	82	232	248
KSUU-PHIK-PGUA-RKSO	17	152	155
KSUU-PHIK-RKSO	35	100	107
KSUU-RJTY-RKSO	12	94	96
KSUU-PAED-RKSO	21	91	95
KSUU-PHIK-PHIK-RJTY-RKSO	18	81	85
KSUU-PHIK-RJTY-RJTY-RKSO	7	46	48
KSUU-KSUU-PHIK-RKSO	8	44	45
KSUU-PAED-PAED-RJTY-RKSO	2	42	42
KSUU-PHIK-RJTT-RJTY-RKSO	4	29	30
KSUU-KSUU-KSUU-PHIK-RODN-RKSO	4	24	25
KSUU-PAED-PHIK-RJTY-RKSO	8	23	25
KSUU-PAED-PAED-RODN-RKSO	10	22	24
KSUU-KSUU-PHIK-RJTY-RKSO	6	19	20
KSUU-PHIK-PGUA-RODN-RKSO	7	18	19
KSUU-PHIK-PGUA-RJTY-RKSO	12	17	19
KSUU-KTOM-KTOM-PAED-RJTY-RKSO	0	16	16
KSUU-PHIK-PWAK-PGUA-RKSO	5	13	14
KSUU-KSUU-PHIK-PGUA-RKSO	6	13	14
KSUU-PAED-RODN-RKSO	0	14	14
KSUU-KSUU-PAED-RJTY-RKSO	12	9	12
KSUU-PHIK-PHIK-PGUA-RODN-RKSO	4	11	12
KSUU-PHIK-PHIK-PGUA-RKSO	0	11	11
KSUU-PHIK-RODN-RJTY-RKSO	0	7	7
⊟KSUU - RJTY	2,199	1,939	2,377
KSUU-PHIK-RJTY	1,353	1,104	1,375
KSUU-PAED-RJTY	409	301	383
KSUU-RJTY	74	84	99
KSUU-PHIK-PHIK-RJTY	33	72	78
KSUU-PHIK-PGUA-RKSO-RJTY	90	58	76
KSUU-PHIK-PGUA-RJTY	36	59	66
KSUU-KSUU-PHIK-RJTY	23	49	54
KSUU-PAED-PAED-RJTY	57	31	42
KSUU-PHIK-PGUA-RODN-RJTY	21	36	40
KSUU-KSUU-PAED-RJTY	27	22	28
KSUU-PHIK-RJTY-RJSM-RJTY	0	25	25
KSUU-KTOM-KTOM-PAED-RJTY	0	22	22
KSUU-PHIK-RODN-RJTY	7	21	22
KSUU-PHIK-RODN-RKSO-RJTY	15	10	13
KSUU-PHIK-RJTT-RJTY	7	12	13
KSUU-PHIK-PGUA-RODN	3	11	11
KSUU-KSUU-PHIK-PGUA-RKSO-RJTY	26	6	11
KSUU-PAED-RODN-RKSO-RJTY	0	7	7
KSUU-PHIK-PHIK-PGUA-RKSO-RJTY	8	5	6
KSUU-PAED-RJTY-RKPK-RJTY	0	5	5
KSUU-PHIK-PGUA-RODN-RKSO-RJTY	0	2	2
⊟KSUU - RODN	1,801	1,888	2,248
KSUU-PHIK-RJTY-RODN	384	576	653
KSUU-PHIK-RODN	521	347	451
KSUU-PHIK-RJTY-RKSO-RODN	280	315	371
KSUU-PHIK-PGUA-RODN	101	147	167
KSUU-PAED-RJTY-RKSO-RODN	157	131	162
KSUU-PAED-RJTY-RODN	54	54	65
KSUU-PHIK-PHIK-RODN	12	32	35
KSUU-PHIK-PHIK-RJTY-RODN	14	29	32
KSUU-PAED-RKSO-RODN	45	22	31
KSUU-PHIK-RJTY-RJTY-RKSO-RODN	48	20	30
KSUU-KSUU-PHIK-RJTY-RODN	15	26	29
KSUU-PAED-PAED-RJTY-RODN	36	22	29
KSUU-PHIK-RKSO-RODN	0	29	29
KSUU-PHIK-PGUA-RKSO-RODN	37	21	28
KSUU-RJTY-RODN	0	23	23
KSUU-KSUU-KSUU-PHIK-RODN	5	20	21
KSUU-PHIK-RJTY-RJTY-RODN	21	16	20
KSUU-PHIK-PGUA-RJTY-RODN	3	18	18
KSUU-PAED-PAED-RODN	4	14	15
KSUU-PHIK-PHIK-PGUA-RODN	22	10	15
KSUU-PHIK-PHIK-RJTY-RKSO-RODN	8	9	11
KSUU-PAED-RODN	34	2	9
KSUU-PHIK-RJTT-RJTY-RKSO-RODN	0	4	4
KSUU-PHIK-RJTY-RKJK-RODN	0	2	2
⊟KSUU - PGUA	163	233	266
KSUU-PHIK-PGUA	121	167	191
KSUU-PHNL-PGUA	3	37	37
KSUU-PHIK-PHIK-PGUA	9	14	16
KSUU-KSUU-PHIK-PGUA	11	5	7
KSUU-PHIK-PWAK-PGUA	8	4	6
KSUU-PGUA	10	2	4
KSUU-PHIK-RJTY-RODN-PGUA	0	2	2
KSUU-KSUU-PGUA	1	2	2
⊟KSUU - PWAK	20	151	155
KSUU-PWAK	20	134	138
KSUU-PHIK-PWAK	0	17	17
⊟KSUU - YSRI	0	17	17
KSUU-PHIK-PGUA-YSRI	0	17	17
Grand Total	13,504	9,494	12,194

Purpose: Data represents information for C005 aircraft in the time period of 1 Jan 2012 to 31 Dec 2014 where cargo (stons)/passenger onload was at Travis AFB, CA. (KSUU) and offload location was at one of the following PACOM locations (PGUA,PHIK,PWAK,RKSO,RODN,RPMZ,WSAP,YSRI,RJTY) along with the route of the missions from onload to offload.
NOTE: Data only represents missions executed in the AMC GDSS G2 system.
Intent of the request is to be used by an IDE student in the ASAM program to write a research paper on C-5M. Requester running a "route analyzer" model developed by AFIT over multiple payloads looking at high frequency of ICAO origin-destination pairs for the C-5M aircraft.
Prepared For: Maj. Christopher Keller, AMC EOS/ASAM 15, DSN: 650-7320.
Prepared By: 618th AOC (TACC)/XOND, DSN: 779-3865, Scott AFB, Il. Data current as of 5 Feb 2015.

Appendix C. C-5 Fleet Breakout

(Source: AMC A4/A4YM C-5 COP, March 2015)

DOVER		436AW
MDS	TAIL #	AMC
A/M	1	
M	15	
TOTAL	18	
IN RERP	1	

TRAVIS		60AW
MDS	TAIL #	AMC
C	2	
B	10	
M	6	
TOTAL	18	
IN RERP	10	

WESTOVER		439AW
MDS	TAIL #	AFRC
B	16	
	16	

MARTINSBURG		167AW
MDS	TAIL#	ANG
A	10	

MEMPHIS		164AW
MDS	TAIL#	ANG
	0	

STEWART		105AW
MDS	TAIL#	ANG
	0	

LACKLAND		433AW
MDS	TAIL#	AFRC
A	13	

AMARG	AMP'd	RETIRED	Type 1000
MDS	TAIL#	LOSING Unit	Storage
A	4		

AMARG	Legacy	RETIRED	Type 2000
MDS	TAIL#	LOSING Unit	Storage
A	32	MB	XV

B+M'S	52
TOTAL	75

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Vita

Major Christopher Keller is currently attending Intermediate Developmental Education through the Advanced Study in Air Mobility (ASAM) program at the U.S. Air Force Expeditionary Center, Joint Base McGuire-Dix-Lakehurst, New Jersey. The ASAM program cultivates a core of mobility officers with an in-depth education in logistics and air mobility operations, to lead the Air Mobility Command in the future.

Chris graduated from the United States Air Force Academy in 2002 with Bachelor of Science degrees in Mathematics and Operations Research. He attended joint specialized undergraduate pilot training at Laughlin AFB, TX. He has since has served in a variety of leadership positions at the squadron and wing levels. Chris has also held numerous supervisory and leadership positions to include serving as an Assistant Director of Operations, Flight Commander, flight safety officer, operations controller, and scheduling officer. He has operational flying and deployment experience during Operations ENDURING FREEDOM and IRAQI FREEDOM

Prior to his current assignment, he served as Executive Officer for the Commander, 621th Contingency Response Wing and a Phoenix Mobility Officer in Air Mobility Command's prestigious leadership development program, stationed at Travis Air Force Base, Calif. He is a senior pilot with more than 2000 flying hours, including 200 combat hours in C-17, and C-21A aircraft.

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14. ABSTRACT

The C-5M, "Super Galaxy", brings significantly more capability to strategic airlift fleet with more powerful and efficient engines. Given the strategic imperatives in the Asia-Pacific region, the C-5M is vitally important to overcome the "tyranny of distance" throughout the Pacific AOR. It is the aim of this research to serve airlift planners with an operationally relevant tool, results and analysis to bridge from national defense strategy to smart tactical employment of a new weapon system. Specifically, this research paper sought to answer questions addressing optimal routes and the impact of routing decisions on tiered enroute support. This quantitative study used regression analysis of aircraft performance and route enumeration. The research identified that the C-5M's capability may justify new route alternatives. These new routes may impact tiered aircraft maintenance capability outside the continental United States. Recommendations to implement more effective and efficient routing are discussed.

15. SUBJECT TERMS

C-5, STRATEGIC AIRLIFT, FUEL EFFICIENCY, PAYLOAD, ROUTING PROBLEM

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